§13. Drift-Kink Instability Induced by Beam Ions in Field-Reversed Configurations

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A beam injection into FRC plasmas is considered to be utilized for suppressing unstable modes. The investigation by means of a three-dimensional macroscale electromagnetic particle simulation shows that a beam injection is effective to keep FRC plasmas stable against the tilt mode [1]. On the other hand, it is also found that the drift-kink instability (DKI) grows rapidly in the vicinity of the field-null line on the midplane and reaches to the saturation level at $t/t_A \sim 2.0 - 3.5$ [2].

We consider FRC plasmas confined by a uniform external magnetic field within the cylindrical conducting vessel. In our simulation, the spatial distribution of beam current is assumed to be in a Gaussian form. For the initial condition of particle simulation, we assume that beam ions are injected along the azimuthal direction with the toroidal velocity v_b and the temperature $T_b = 0$. As a result, the plasma profile on the midplane of the FRC plasmas considered in our model is very similar to the Harris equilibrium. That is, a strong antiparallel magnetic field exists at the both sides of the peaked beam current, the widths of which is comparable to the typical ion Larmor radius ρ_{i0}.

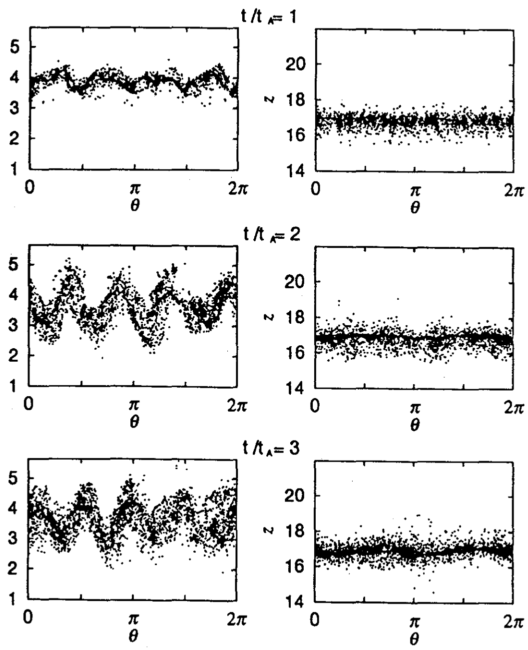

Fig. 1. Time sequential plots of beam ions projected on (left) the $\theta - r$ space and (right) the $\theta - z$ space.

We plot the distribution of all beam ions in Figure 1. A wavy structure is generated in the $\theta - r$ space as time elapses, thus the beam ion distribution changes dramatically from the initial distribution. On the other hand, the ion distribution in the $\theta - z$ space hardly changes. Since the magnetic field is dominated by the z-component on the midplane, the deviation of the beam profile develops in the perpendicular direction of the magnetic field.

The strong deformation of the magnetic profile simultaneously occurs in the vicinity of the field-null line, where the current density with a beam component steepens. This mode propagates in the same direction as the beam circular motion with the real frequency $\omega_r = 0.13\omega_{ci}$. Judging from the mode pattern of the perturbed magnetic field ΔB_z, it seems reasonable to suppose that this unstable mode corresponds to the DKI driven by the peaked current.

Time histories of the amplitude $\Delta B_z^{(n)}$ of each toroidal mode ($n = 1 \sim 7$) are shown in Figure 2, where the magnetic field is measured at the initial position of beam ions r_b on the midplane. The $n = 4$ mode grows dominantly and its amplitude is saturated in the early phase of the simulation. This period corresponds to the time when the initial peaked current profile with the half-width $L \ll \rho_{i0}$ relaxes to the smoothed profile of $L \geq \rho_{i0}$. This suggests the DKI is nonlinearly saturated as a result of the relaxation of the current profile. In other words, the ion beam which is localized in an unmagnetized narrow region ($L \ll \rho_{i0}$) spreads over the magnetized wide region ($L \geq \rho_{i0}$) as a result of the nonlinear evolution of the DKI. Thus, the ion magnetization effect may stabilize the DKI for $L \geq \rho_{i0}$. It is also found that the saturation level of the amplitude and the growth rate γ of the DKI tend to increase as the beam current increases.

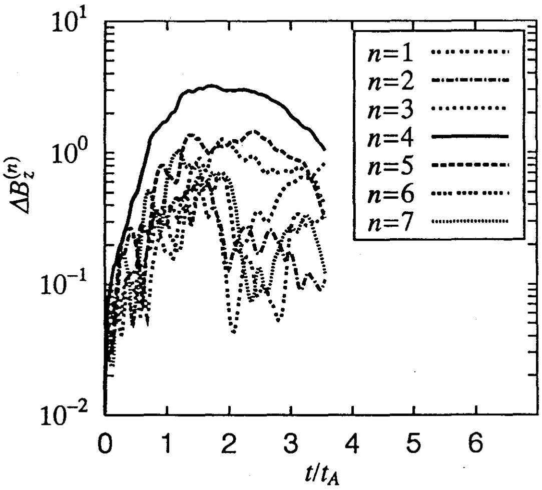

Fig. 2. Time history of the mode amplitude $\Delta B_z^{(n)}$ for different values of toroidal mode number n.

References
1) Horiuchi, R., Nishimura, K., Watanabe, T.-H., and Sato, T., Nucl. Fusion (in press).
2) Nishimura, K., Horiuchi, R., and Sato, T., Phys. Plasmas (in press).